A study on the dependence of ocean planet climate on solar constant: influence of oceanic heat transport in the case of large absorption coefficients of gray atmosphere

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1. Introduction

In order to reveal the diversity of climate realized on planets with water and climate stability, our research group has been exploring climates on idealized planets. Ishiwatari et al. (2007) (INTH07) investigated solar constant dependence of climates on swamp ocean planet using a 3-dimensional atmospheric general circulation model, although oceanic heat transport is not considered. Since oceanic heat transport also affects planetary climates, for example, Rose (2015) (R15) explored climates on a planet globally covered with ocean (referred to as ‘’ ocean planet”, here) with a coupled atmosphere-ocean-sea ice model, and showed the importance of oceanic heat transport for the climates. Recently, as an extension of INTH07, we also have investigated solar constant dependence of ocean planet climates with our coupled model. Representing ocean general circulation obviously changes atmospheric fields. However, the displacement of ice-line is small and there is no qualitative change of climate regime diagram which represents the relation between solar constant and ice-line latitude. We imagine the reason is that the variation of temperature with solar constant in partially ice-covered states obtained from gray radiation setting of INTH07 is quite smaller than that in R15. Therefore, we perform further experiments in the case of large absorb coefficients. In this presentation, the experimental results will be shown.

2. Model and Experimental setup

The model used here is our constructing coupled atmosphere-ocean-sea ice model. The atmosphere model is DCPAM, in which the 3-dimensional primitive equations are solved. Most of the atmospheric setting is same as that in INTH07, except absorb coefficients of water vapor and dry air in the gray radiation scheme are replaced with larger values, 1×10^{-1} and 1×10^{-5} [m^2/kg], respectively. The ocean and sea-ice model are zonally averaged 2-dimensional models. In the ocean model, the hydrostatic Boussinesq equations are solved, and mixing due to mesoscale eddies and convection is parameterized. The sea-ice model is a vertically 1-dimensional thermodynamics model, and the transport is represented by horizontal diffusion. The value of surface albedo is 0.5 if surface temperature is lower than 263 K, otherwise 0, but the value on grid-point is given considered the sub-grid distribution of surface temperature. In addition to experiments with the coupled model, in order to evaluate the effect of oceanic heat transport, we also perform experiments in which dynamic ocean is replaced with slab ocean. The number of atmosphere model grid is 64x32x16. The number of grid points on the ocean and sea ice models is 64x60 and 64, respectively. For most cases, the initial condition is a rest atmosphere and ocean with 280 K, but various solutions are also used. The temporal integration for slab ocean cases is basically performed over about 300 years, and, for dynamic ocean cases, over about 30,000 years with periodically synchronous coupling.

3. Results

By specifying absorb coefficients larger than that in INTH07, features of climate regime diagram are significantly changed. In dynamic ocean experiments, partially ice-covered states are obtained over $1040 \leqq S \leqq 1055$ W/m^2, where S is the solar constant. The solar constant at which partially ice-covered states are obtained becomes about 300 W/m^2 smaller and the range of solar constant becomes much narrower. We also confirm the appearance of runaway greenhouse state for $S > 1070$ W/m^2. The latitudinal extent where large ice-cap instability occurs is wider. Although it is not easy to obtain partially ice-covered state whose ice-line is lower than 40 degrees latitude, we can discover stable partially ice-covered state with about 30 degrees ice-line when initial state and variation of solar constant are carefully chosen. Because this behavior indicates two branches for the partially ice-covered state, similar to that in R15, and we will carefully investigate the existence of solutions with low ice-line latitude. In slab ocean experiments, there are no partially ice-covered states. Therefore, we consider partially ice-covered states in dynamic ocean experiments are maintained by oceanic heat transport. Note that the setting here produces the large variation of temperature with solar constant, as calculations in R15, and the parameter range over which partially ice-covered states are obtained is potentially very narrow. It is possible that the resolution and formulation of models strongly affect the results. To evaluate the probabilities, it is necessary to conduct further experiments using slightly different parameters.

Keywords: ocean planet, dependence of climates on solar constant, a coupled atmosphere-ocean-sea ice model